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A Novel Onboard-gateway-based Mechanism to Improve TCP Performance in Aeronautical Satellite Networks

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Abstract

The IP-based networks on aircraft serve to support Internet services via satellites. However, in aeronautical satellite hybrid networks, the TCP protocol performance often deteriorates due to improper decreases and slow recovery of the congestion window. This paper proposes a window size determination and notification mechanism, onboard-gateway-based mechanism (OGBM), which is based on the onboard gateway in the networks on aircraft. A cross-layer approach is adopted by the onboard gateway to obtain the satellite link bandwidth information. And then, by the gateway, through changing the receiver's advertised window field in ACK packets, TCP sources are notified of the window size of each TCP source calculated on the ground of bandwidth delay product and flow numbers. The mechanism is able to avoid improper changes of TCP window and serve multiple users. Simulation results show that the mechanism with the fairness index close to 1 improves TCP performance in aeronautical satellite networks.

Keywords: congestion control; TCP; gateway; aeronautical satellite network

1 Introduction

With rapid development of global air transport in 21st century, an increasing number of people have spent more time on flight every year. This means ever-more-growing needs for providing them with new information and data service, which increases the importance of developing aeronautical networks.

In comparison with the VHF air ground data link able to deliver communication services in some areas^[1-2], the satellite network which has vast coverage is more qualified to meet the requirements of aeronautical communications. Moreover, the satellite network is actually the only way when aircraft flying over oceans and deserts. The existing aero-

nautical mobile satellite system (AMSS), communications navigation surveillance and air traffic management system (CNS/ATM)^[3] are the best examples for the satellite network in service to the air transport.

An integration of onboard network into a terrestrial network via a satellite network will create openings for passengers on flight to have access to Internet and communication services.

In order to provide the aeronautical satellite network with TCP/IP services, some relevant modification in TCP protocols should be made, or else it can not work effectively. The decaying performance has its origin in long propagation delays, high link error rates and asymmetric link bandwidth^[4]. Considered to be responsible for the congestion, packet drops caused by link errors also lead to TCP congestion and window decreases. On the other hand, the long propagation delay makes the window in-

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crease very slowly in the period of either startup or recovery after the packet drops. Therefore, the usage of a standard TCP protocol in an aeronautical satellite network surely is the source of the quite low utilization factor of the satellite link.

Over the past decade, a number of TCP modifications have been proposed, aiming to improve the performance of the TCP protocol in satellite environments^[4-7]. Most of them focused on end-to-end enhancements in the standard TCP window adjustment algorithm, which, however, usually are ineffective, or difficult to implement or inadequate to solve all problems. For example, TCP-Peach^[7], a well-known version, is difficult to be used in onboard networks because of its requirement of altering the satellite and ground network protocols.

To improve the performance^[8] to some degree, splitting the TCP connection into segments proves effective, for it separates high-latency and noisy network segments off the rest of network. However, this improvement is very limited on condition that the satellite link is the main bottleneck of the network.

The key to solving the problem seems to lie in avoidance of improper changes of TCP windows. A research indicates that, in the space Internet, it is better to use a fixed rate in place of a varied window^[9].

A TCP splitting protocol, AeroTCP^[10], in which the TCP connection is split at the gateway on the aircraft is introduced in the aeronautical satellite network. In AeroTCP, the window adjustment is obviated since the bandwidth of the satellite link is fixed and only one flow in the satellite link exists. AeroTCP possesses a higher performance than most end-to-end TCP protocols, but violates the end-to-end semantics of transport layer protocol. AeroTCP does not illustrate how the TCP source knows the bandwidth of the satellite link. Furthermore, the satellite link permits only one TCP flow devoid of the way for onboard TCP clients to share it thus making them unable to use the network simultaneously.

In this paper, in order to improve TCP per-

formance in aeronautical satellite networks, a mechanism is devised on the base of the onboard gateway to avoid improper changes of the congestion window, and thereby supports multiple onboard users.

2 Aeronautical Satellite Network

Fig.1 illustrates the scheme of an aeronautical satellite network which is composed of three major segments: the onboard network on aircraft, the satellite network, and the ground network^[10].

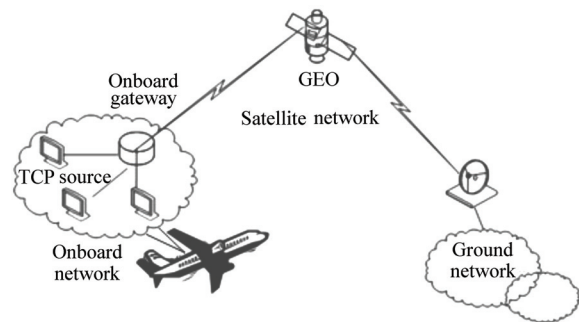


Fig.1 Aeronautical satellite network.

The onboard network on aircraft is an IP-based LAN. The onboard gateway is a border node both of the onboard network and of the satellite network. There is an up and down link between the onboard gateway of aircraft and the GEO satellite. The end systems in the onboard LAN are all connected to the onboard gateway, so that they are able to have access to the ground networks via the satellite network.

When passengers use TCP/IP via the onboard LAN on flight, in the satellite link, there may be many TCP flows passing through the onboard gateway. Obviously, the satellite link will be a bottleneck of the whole network if its available bandwidth is smaller than that of wired links.

In order to enable TCP to make full and fair use of the satellite link, a novel mechanism is suggested as follows.

3 An Onboard-gateway-based Mechanism

In this mechanism, the onboard gateway is used to assist TCP sources to decouple the per-

formances of congestion control and error control in TCP. The onboard gateway serves to eliminate congestion and assign bandwidth resource while the TCP source acts to retransmit the lost packets only.

The onboard gateway has the duty of collecting information about the bandwidth delay product (BDP) of the satellite link and the number of TCP flows as well as carrying out a fair assignment of the bandwidth to each flow. The window size of each TCP source, which is defined by the onboard gateway, does not reduce in case of packets dropping. Because the sum of window sizes of all active TCP sources in the onboard network equals to the BDP, the utilization of network resources can be maximized resulting in avoidance of any congestion.

As this onboard-gateway-based mechanism (OGBM) is only concerned in the onboard network, it is well compatible because it dispense with the need for modification of the protocols in the satellite and ground networks.

The implementation of OGBM will be discussed in detail below.

3.1 Onboard gateway

(1) Getting the satellite link bandwidth

The underlayer communication equipment of the onboard gateway is connected to the satellite network. A cross-layer approach is used to acquire the uplink bandwidth B_w assigned by the satellite.

Easy in practice and different from the approach of providing TCP information as an input to allocate resources by a double cross-layer interaction in each TCP host^[11], the gateway only needs to collect the information of the already allocated resources.

In every super-frame, the MAC layer obtains the allocated resources assigned by the satellite and the information about the position of the slots (time or frequency). Therefore, the uplink bandwidth can be acquired in the form of the number of packets can be sent out per unit time.

Each time the amount of allocated radio resources changes, an internet control message proto-

col (ICMP)^[12] message is generated. This cross-layer message, which contains resources information from the MAC layer, is transferred to the gateway processing software. This approach proves to be flexible and efficient because the ICMP messages are conveyed through selected holes in the protocol stack, thus enabling the cross-layer communications to make unnecessary a layer-by-layer processing.

(2) Calculating the basic window size

The onboard gateway maintains a flow-state table which registers the flow ID and the latest packet transmission time of each TCP flow. The flow ID is defined by the source address and the port. Then the onboard gateway can distinguish flows and their activities, and accordingly acquire the number of the active TCP sources in the onboard network, N_F .

Since the propagation delay of the GEO satellite network is much larger than those of the onboard network and the ground network, the round trip time (RTT) of each TCP flow is approximately equivalent to the RTT of the satellite network, R_S , which can easily be estimated by packet pairs, or simply replaced by a typical value of the GEO satellite system.

Generally, the right congestion window size is the product of the delay and the available bandwidth, so that the network resource can be fully used and the congestion can be avoided. In the aeronautical satellite network, exists the following relationship

$$\sum_{i=1}^{N_F} W_i = B_w R_S \quad (1)$$

where W_i is the congestion window size of i th TCP flow.

For the sake of simplicity, the priority will not be discussed here. The window sizes of each TCP source are all the same. So the basic window size determined by the onboard gateway is

$$W_B = \frac{B_w R_S}{N_F} \quad (2)$$

The onboard gateway checks the flow-state ta-

ble every time interval of R_S , and refreshes N_F , from which is figured out W_B in Eq.(2).

(3) Notification and reassignment method

In the header of ACK packets, exists a field of a receiver's advertised window which a TCP receiver uses to notify the source of its free buffer size to eliminate overflow. Let W_{Ai} denote the receiver's advertised window size of the i th TCP flow, then W_{Ai} is an upper limit of W_i .

When an ACK packet runs through the onboard gateway, the receiver's advertised window field in it is checked. If $W_{Ai} > W_B$, the gateway will modify the receiver's advertised window field by setting $W_{Ai} = W_B$.

Otherwise, if $W_{Ai} < W_B$, the receiver's advertised window field remains unchanged. The surplus resource ($W_B - W_{Ai}$) will be reassigned to other flows by increasing W_B . Let N_S denote the number of flows when $W_{Ai} < W_B$. Now, W_B will be updated to

$$N_S = N_S + 1 \quad (3)$$

$$W_B = W_B + \frac{W_B - W_{Ai}}{N_F - N_S} \quad (4)$$

Reset $N_S = 0$ each time after W_B is calculated according to the Eq.(2).

Because W_B is often refreshed according to Eq.(2) and Eq.(4), the bandwidth resource can be almost totally assigned to all the active TCP flows.

After having been checked and updated, the ACK packet is transferred to its TCP source. Then the receiver's advertised window field is used to notify the TCP source of the congestion window size carried by the ACK packet.

3.2 TCP Source

When the source receives the ACK packet, it will take the congestion window size out of the receiver's advertised window field, and then reset its congestion window size according to the notification. The congestion window size will remain unchanged unless the TCP source receives another new notification.

When a packet drop occurs, it is regarded as a

link layer corruption without decreasing window size. Whenever a duplicated ACK is received, only an immediate retransmission of the lost packet is necessary.

4 Simulation Evaluation

NS-2 simulation software is used to evaluate the performance of OGBM.

When there is only one TCP flow in the network, all the bandwidth can be assigned to it. In this case the performance of OGBM is the same as that of AeroTCP. And considering the fact that AeroTCP is unable to support more than one flow, OGBM is compared with TCP splitting (SACK) in the simulation. By using the splitting scheme, the onboard gateway works as both a receiver and a source.

Fig.2 shows the simulation topology in which a GEO satellite module is used. Here, S_i is the source in the onboard network, R_i is the receiver in the ground network, OG is the onboard gateway, and GS is the ground station.

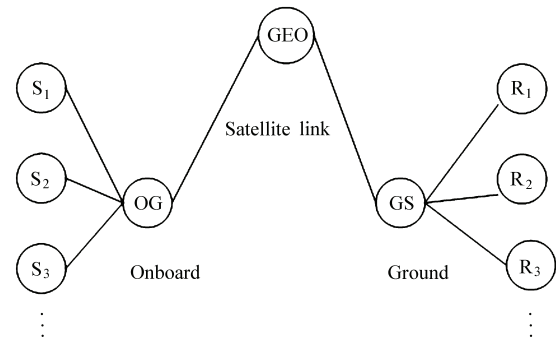


Fig.2 Simulation topology.

Supposing that the bandwidth of each link is 2.0 Mbps, the delay of both satellite links 125 ms, the link delay between GS and R_i is $3 \cdot i$ ms ($i=1, 2, 3 \dots$), and the delays in the onboard network are ignored.

The source transfers data to the receiver by FTP with a packet size of 1 000 bytes.

A random error module is added to the satellite link. The packet dropping rate (PDR) is set from 10^{-5} to 10^{-1} .

Fig.3 compares the utilization of the OGBM satellite link with that of the TCP splitting.

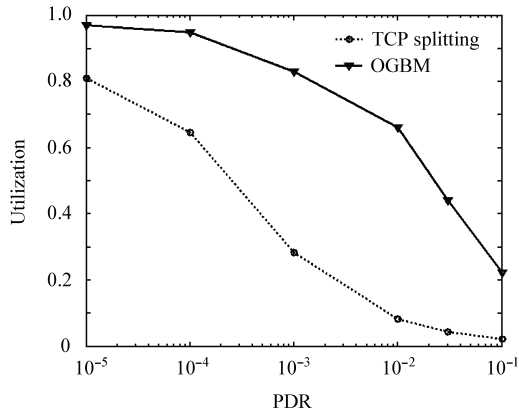


Fig.3 Utilization of different packet drop rates.

From Fig.3, it can be seen clearly that the link utilization of OGBM is always higher than that of TCP splitting whether the PDR is low or high. For TCP splitting scheme, when the PDR increases, the link corruption will cause the TCP connection on the satellite links to decrease the congestion window, which leads to performance degrading. In contrast, OGBM can avert congestion and keep the right window size from start to finish making the throughput and the satellite link utilization as high as possible. And with the PDR higher than 10^{-2} , the utilization of OGBM drops, which is attributed to the augment of lost packets and the packets retransferred by the TCP source in the onboard network; even so, the utilization of OGBM is still much higher than that of TCP splitting.

Fig.4 compares the time needed to transfer a 2.5 MB file by either OGBM or TCP splitting.

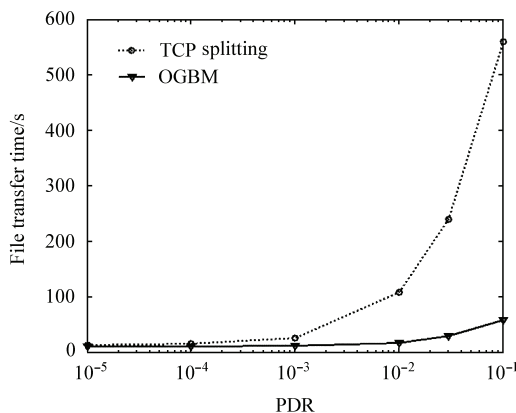


Fig.4 Time needed to transfer a 2.5 MB file.

From Fig. 4, the time needed by OGBM is less than that by TCP splitting, and, especially, the dif-

ference becomes remarkably large as the PDR turns higher than 10^{-2} which corroborates the high efficiency of OGBM. In OGBM, the TCP source can consistently send packets at the rate of satellite link bandwidth, while in TCP splitting, though the on-board TCP can keep the congestion window, the satellite TCP can not, which makes the actual throughput very low when the PDR increases.

In order to evaluate the fairness of coexistence of flows in the network, the fairness index F is defined as^[13]

$$F = \frac{(\sum_{i=1}^{N_F} \frac{B_i}{B_w})^2}{N_F \cdot \sum_{i=1}^{N_F} (\frac{B_i}{B_w})^2} \quad (5)$$

where B_i is the actual bandwidth assigned to flow i (from S_i to R_i). Let the actual RTT of the i th flow be D_i , then B_i can be calculated.

$$B_i = \frac{W_i}{D_i} \quad (6)$$

In this simulation, S_1 - S_5 are supposed to transfer data to R_1 - R_5 respectively, and the number of the active flows is changed by starting and stopping the sources.

The fairness indexes are listed in Table 1, which shows very high fairness possessed by OGBM. Moreover, it should be pointed that the minor variation in fairness indexes is caused by the difference between delays of the coexistent flows rather than by the change of flow numbers.

Table 1 Fairness index

Active flows	Fairness index
1, 2	0.999
1, 2, 4, 5	0.998
1, 2, 3, 4, 5	0.998
1, 5	0.997

5 Conclusions

In this paper, an IP-based aeronautical satellite network is investigated, especially focusing on the way to improve TCP performance in providing on-board TCP/IP services.

In an attempt to avoid the throughput degradation and make full and fair use of the bandwidth,

OGBM is proposed as a window size determination and notification mechanism, which is based on the onboard gateway. A simple cross-layer approach is used to obtain the satellite link bandwidth at the gateway. The window size of each TCP source is calculated on the ground of the BDP and the number of the active flows. ACK packets are used to transfer the assigned window size from the onboard gateway to TCP sources. Congestions and improper decreases of TCP windows are thus avoided. The proposed mechanism maintains the end-to-end semantics and supports multiple onboard users.

Simulation results attests to the effectiveness of the proposed mechanism with high efficiency and fairness. Furthermore, because this mechanism dispenses with the need for modifying protocols in the satellite networks or the ground networks, it is possessive of good compatibility.

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